Environmental Change Research Group

Revealing Nature’s Past – 2013 Summer Workshop

Paleoecology, Climate Change, and the Dynamic Character of Landscapes

Erin M. Herring and Daniel G. Gavin
Department of Geography
University of Oregon
Eugene, OR 97403
541-346-5787
dgavin@uoregon.edu

Introduction

The goals of these lessons are to provide students with an appreciation of the dynamic character of natural landscapes, their changes over thousands of years of climate change, and an understanding of some of the causes of those changes. Paleoecology, the study of ecological questions over time scales longer than directly observable by humans, is inherently interdisciplinary. Many ecological questions and theories are greatly enhanced from a long-term view, as what we see in the natural world today may not be very representative over longer periods of time. This is for two major reasons. First, humans have had a major impact on nearly all environments on Earth, especially during the last 200 years. Second, climate and the “template” of the Earth is always changing. Over the past hundreds, thousands, and millions of years, climate has changed in countless ways. Earth surface changes from changing sea levels (and lake levels), the building and erosion of mountains, and shifting ocean currents. Thus, an understanding of geological processes and the causes and patterns of climate change is necessary context for paleoecologists. Paleoecologists’ data are (normally) fossil records—either the very old fossils that are imprinted in rock or recent fossils that are actual body or plant parts that are preserved in a low oxygen setting such as sediment. Thus, paleoecologists must have a strong interest in morphology and identifying species from just a few pieces of evidence. Finally, paleoecologists are primarily ecologists, and specifically ecologists with a broad view of nature, in both space and time. Thus, the *geographical perspective*[1], that there are many processes operating to explain spatial patterns, is the fundamental approach of most paleoecologists. This means having to consider factors such as how species disperse, the spatial pattern of climate on the landscape, evolutionary changes as species adapt to climate change through time, and specific events in Earth’s history. This vast array of types of information needed to

---

[1] http://www.nationalgeographic.com/xpeditions/guides/geogpguide.pdf

understand nature's past makes the science of paleoecology very exciting, relevant, and inherently interdisciplinary science for decades to come.

One of the most common means of accessing the historical changes on landscapes is through pollen records preserved in sediments. The lessons, which will require several class periods, involve 1) understanding the main causes of past climate changes, 2) learning the common forest trees and vegetation types of western Oregon, 3) learning the tools of paleoecology: coring, sediment processing, and pollen analysis, 4) collecting data on pollen types observed on prepared microscope slides, and finally 5) plotting data and interpreting the results. A sixth exercise addresses how paleoecological data is archived, accessed, and analyzed. The lessons are most effective if a classroom has a digital projector and a compound light microscopes that have a total magnification power of at least 100X (ideally 200X or 400X) with a stage that can moved with two stage-control knobs so microscope slides can be scanned. PowerPoint slides are provided for several of the five lessons, though they are not necessary to use. We provide enough material (including handouts designed for the students) so that one or two lessons can be covered in one 45-minute session.

Lesson 1: Climate Change since the Pleistocene

Questions to be considered:
What is climate?
How has Earth's climate changed over the past 2 million years?
What caused past climate change?
Why do ecologists study past climate?

Climate is the long-term pattern in weather, or a description of the typical conditions of an area normally defined by the variables of temperature, humidity, precipitation, atmospheric pressure, wind, and cloudiness. Climate varies greatly over space, from the equator to the poles (affecting *seasonality*), with distance from ocean (from *maritime* to *continental* climates), and from low to high elevation (affecting temperature and precipitation). The vegetation form (types of species, density and height of plants) is affected mainly by the climate.

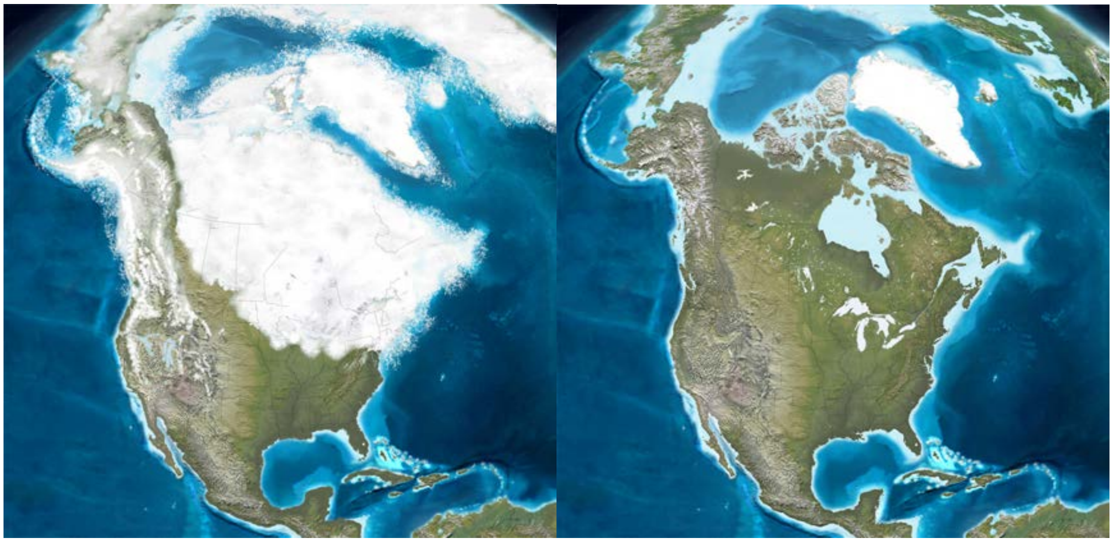
Climate has varied greatly over time. For example, **droughts** (extended periods of below-average rainfall) affect regions for multiple-year periods, such as in Texas from 2009-2012. Such climate events affect agriculture as well as natural processes, such as wildfire and the distribution and abundance of plants and animals. Climate events may also last centuries, such as a cold period affecting much of the planet in the 1700's and early 1800's, called the Little Ice Age. The "real" Ice Ages, however, dwarf all of these climate events. Over the past 2.6 million years (the **Quaternary period**), and especially over the last 1.6 million years, the Earth's climate has fluctuated between cold periods called **glaciations** and warmer periods called **interglaciations**. Our current interglacial is the **Holocene epoch**, which began 11,600 years ago, whereas the prior glacial period is the **Pleistocene epoch**. The glacial periods were marked by greatly varying climates, from the coldest periods called **Glacial Maximums** to more moderate periods. Glacial Maxima have recurred on roughly 100,000-year intervals, with the most recent maximum (the **Last Glacial Maximum or LGM**) occurring from 22,000 to 19,000 years ago. The warm interglacial periods last roughly 15,000 years in length; we had been heading into the next glacial period (slowly) prior to human modification of the climate.

There are three major controls of Earth's climate: incoming solar radiation (**insolation**), **ice extent**, and **greenhouse gases**. These have changed dramatically from the LGM to the present. Earth's orbit varies slowly on cycles lasting from 20,000 to 100,000 years. The slow changes in the Earth's orbit, called **Milankovitch cycles**, were first calculated by **Milutin Milanković**, who was interested in the potential of slight changes in Earth's orbit to cause the ice ages. These Milankovitch cycles involve the shape of the orbit (also called *eccentricity*), the tilt of Earth's axis (*obliquity*) and the seasonal *precession* of the perihelion (the closest Earth-sun distance) which all combine to affect insolation (more technically described as *the latitudinal distribution and seasonal cycle of insolation*). The important result of these cycles is that the amount of sun energy reaching northern areas (northern Canada and the arctic) during the summer can vary quite a bit (±10%). When northern summer insolation is low, snow does not completely melt and ice sheets begin to accumulate. The Milankovitch cycles are the pacemaker of glaciations.

The extent of glacial ice sheets causes more cooling due to a **positive feedback** in the climate system. Since ice is light in color it has a high **albedo** (reflectivity). The high reflectivity means that most insolation is reflected back into the atmosphere (some of which escapes back to space) and not absorbed, resulting in cooler temperatures near the land (and hence the positive feedback). The cooler temperatures promote the accumulation of more ice, and even affect global temperatures (for example, the southern hemisphere cooled during the LGM even though it was far from the major ice sheets). The ice was two miles thick in northern Canada. Water tied up in the ice sheets lowered the global sea level by 390 feet (120 meters). Naturally, when summer insolation increased, it required a long period for the ice to melt completely (from 16,000 to 8,000 years ago, though most all ice in western Canada was gone by the Holocene).

Greenhouse gases include water vapor (invisible to the eye and the most common greenhouse gas), carbon dioxide, and methane. These gases, although a small portion of the atmosphere (which is mostly nitrogen and oxygen), play a very important role in the climate. Atmospheric gases are mostly transparent to the energy of the sun, which passes through the atmosphere and is absorbed by the land and water. This warms Earth's surface. The energy is now emitted from the Earth's surface as heat energy (radiation with a much longer wavelength: infrared or longwave radiation), which is re-absorbed by the greenhouse gases. It is then re-emitted in all directions, much of which returns to the ground. This process occurs 24-hours a day (day and night), and the result is that Earth's average temperature is a comfortable 57°F. In the absence of these gases the average temperature would be about 32°F. So, more greenhouse gases will increase Earth's average temperature. Carbon dioxide and methane were at a lower concentrations during the LGM, thus increasing the amount of outgoing longwave radiation escaping from Earth's surface and atmosphere to space. The cause of the lower greenhouse gas concentrations during the LGM is complex, as it is tied to plant growth and decay and ocean circulation (gases dissolving into and ventilating out of the ocean), and these processes are affected by climate itself.

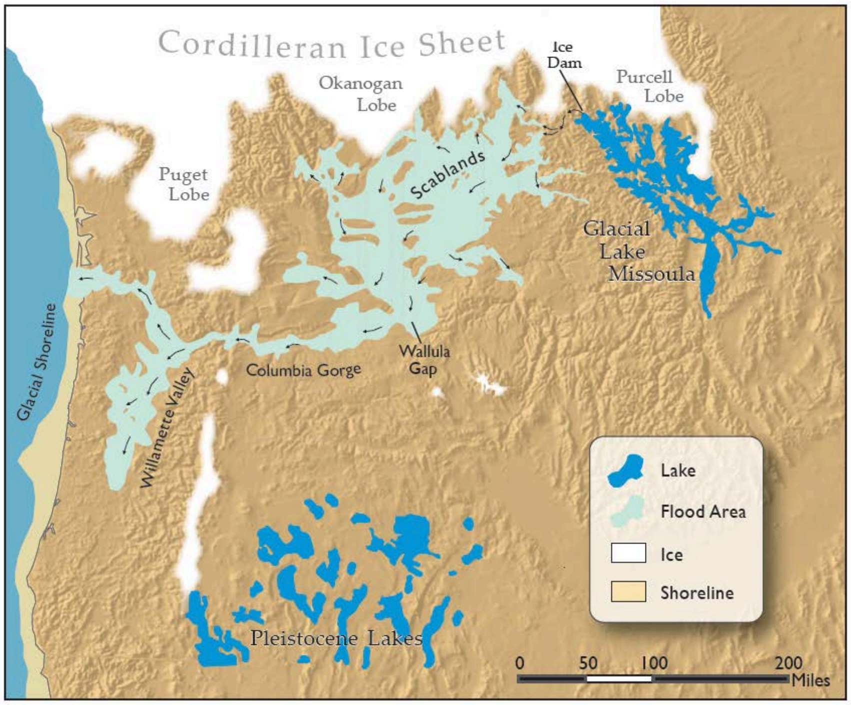
For detailed presentation of the issue of increasing greenhouse gases and ongoing climate change, we recommend the National Climatic Data Center (http://www.ncdc.noaa.gov/cmb-faq/globalwarming.html).



Maps of North America during the Last Glacial Maximum (LGM, 21,000 years ago) and present. Note the lower sea level during the LGM, as seen by an enlarged Florida and Yucatan Peninsula. These maps show an "ice free corridor" east of the Rocky Mountains, which was likely not present during the LGM. From http://cpgeosystems.com/products.html

At the end of the last ice age (20,000 years ago), a glacier formed an ice dam on the North Fork of the Clark River in Montana. When the dam broke, it caused a 500-foot-high wall of water to sweep west over Washington, where the waters scraped off layers of soil, leaving behind a landscape known today as the "Scablands".

The flood continued west and south to Oregon and through the Columbia River gorge. At Portland, the water flooded the Willamette Valley (briefly reversing the flow of the river) and finally headed northwest to the mouth of the Columbia where the flood waters, and the debris they carried, emptied into the Pacific Ocean.



Environments of the Pacific Northwest from the LGM to the late Glacial. Ice extent in Oregon dates to the LGM, while the Puget Lobe reached its maximum at 16,800 years ago. The Missoula Floods, several of which occurred around 15,500 years ago. From the Student Atlas of Oregon (http://www.studentatlasoforegon.pdx.edu).

We have overwhelming evidence for the following general pattern of climate change that has occurred in western Oregon and Washington. This evidence comes in the form of evidence of past glacial extent (moraines) and past lake-levels, as well as from pollen records recording past vegetation.

The Last Glacial Maximum: A large ice sheet, up to several miles thick, covered most of Canada. Cold winds coming off of the ice sheet moved east-to-west across Oregon, reducing the amount of moist air that normally moves in from the Pacific Ocean. Cooler summer temperatures meant the "high desert" of eastern Oregon was much wetter than today, and the lakes of that region were very large where today there are only small lakes or salt flats.

The Late Glacial (16,000 to 12,000 years ago): Changes in Earth's orbit resulted in an increase in solar insolation in the summer. By 11,000 years ago, there was 8% more summer insolation than occurs today. However, there was still a massive ice sheet over Canada, which required thousands of years to melt away. Not until 14,000 years ago did the ice loss accelerate during a major warming. At this time, great floods occurred when ice-dammed lakes burst out of Montana, scoured eastern Washington, and backed up the Willamette Valley all the way to Eugene.

Many large mammals, now extinct, existed in Oregon. A large camel (Yesterday's camel), giant sloths, mastodons, the huge short-faced bear, the American lion, and many others, contributed to what must have been a North American 'Serengeti'. Humans arrived to North America about 13,700 years ago (based on the strongest current evidence), and these large mammals did not survive into the Holocene. While climate change may have contributed to their demise, the impact of human hunters was likely essential to cause the extinctions.

The Early Holocene (11,600 to 8,000 years ago): Once the ice sheet was nearly entirely melted, and greenhouse gases in the atmosphere increased. Summer insolation was 10% higher than it is today, causing our summers to be warmer and drier during the summer. Oregon summers were more like those in central California. Forest fires were more common than today.

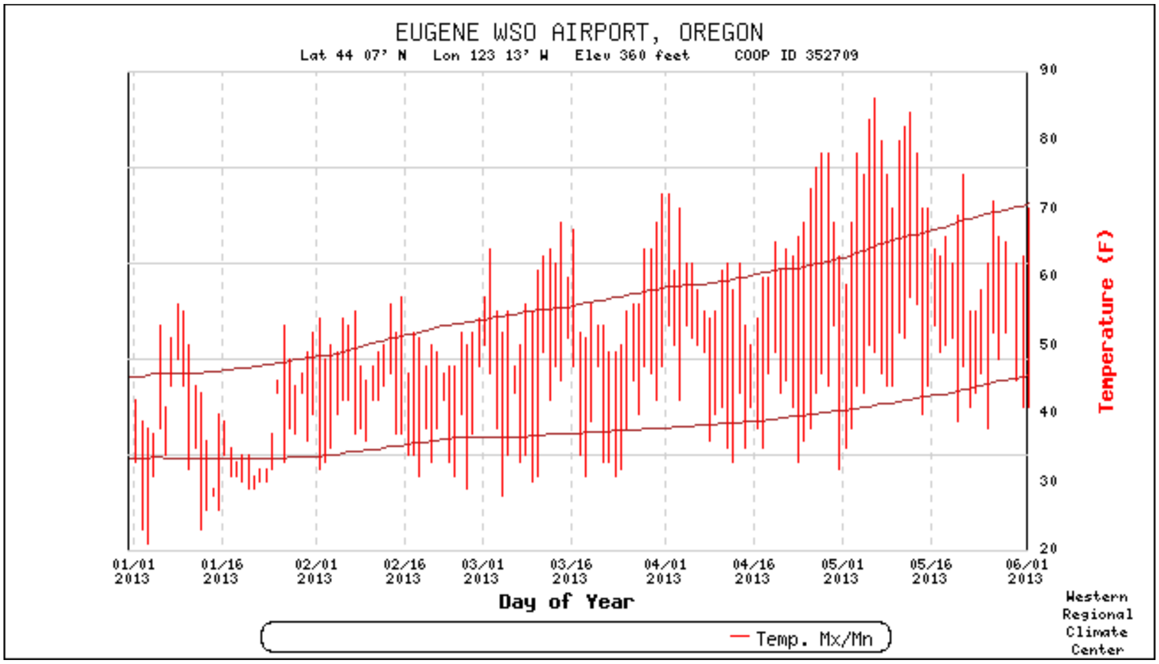
The Middle and Late Holocene (8,000 years ago to present). Crater Lake was formed 7600 years ago with the eruption of Mt Mazama, plastering central Oregon and beyond with a thick deposit of ash. Through this period, summer insolation decreased, summers became cooler, and winters became wetter. Forests generally become denser with trees and composed of species that require moisture. The large old-growth forests, as still occur in some places, were able to form due to the decrease of fire and increased rainfall.

The Earth system is a wonderfully complex set of interacting things: climate, plants, ice, atmospheric gases, etc, and these interactions are the focus of a large community of scientists. The fact that these interactions are important can be seen from the many shorter-term climate fluctuations that cannot be explained by changes in orbital parameters. For example, when the climate warmed at 14,000 years ago, it fluctuated for a few thousand years and then fell again into a 1300-year cold period called the Younger Dryas. Such changes may occur from the effects of melting ice sheets and changing ocean circulation. Variability in solar output also appears to cause some of these shorter-term climate fluctuations, but in general solar output is considered to vary too little to cause major changes in climate. See the figure at the end of this lesson for a general view of climate change of the last 16,000 years in the northern hemisphere.

Suggested classroom activities and demonstrations:

1. Climate concepts.

Show climate data (monthly average temperature and rainfall) for your town. Compare the current weather of the day with the long-term average climate. (To really do this in a neat way, you can show a graph of the daily temperature for the last several days compared to the long-term average. See http://www.wrcc.dri.edu/cgi-bin/cliMAIN.pl?or2709 then click Graph and Lister under Daily Data on the left side. Enter the date range and select temperature min and max. The plot below shows the normals (the 30-year average) of daily high and low temperature, and the vertical red lines show the measured high and low for the day in the year 2013. Examine the temperatures in January relative to the average. Warm and cold periods are seen.



2. Discussion of the controls of Earth's global climate. Graphical depictions of the greenhouse effect are useful, such as interactive animations: http://environment.nationalgeographic.com/environment/global-warming/gw-overview-interactive/

3. The cause of the seasons and demonstration of effects of changing Earth's axis tilt.

Basics: http://www.teachersdomain.org/resource/ess05.sci.ess.eiu.seasonsgame/

Using a globe (larger the better), show how the Earth orbits the sun in a single plane (the plane of the ecliptic), but that the axis of the Earth is tilted (23.5° from the vertical) and that the axis tilt does not change (axial parallelism). With a bright light show how the northern hemisphere is more or less directly illuminated depending on which part of the orbit. Now increase the tilt of the earth and repeat. Is the northern hemisphere more or less illuminated during the summer (the "high-sun" season)? This is equivalent to the early Holocene state. Now decrease the tilt so that the axis is close to vertical. This is more similar to the conditions when ice sheets grow.

4. Draw a temperature history from the LGM to the present.

Convey the amount of time covered, in terms of number of centuries.

Convey the idea of temporal scale, and variation day to day (weather), within a year (seasons) to variation between years (climate).

Show map of the Student Atlas of Oregon (above). Define the Pleistocene and Holocene, label on the temperature curve.

5. Show images of Glacier Bay Alaska to convey the type of environment that occurred in Puget Sound (Seattle) about 16,000 years ago.

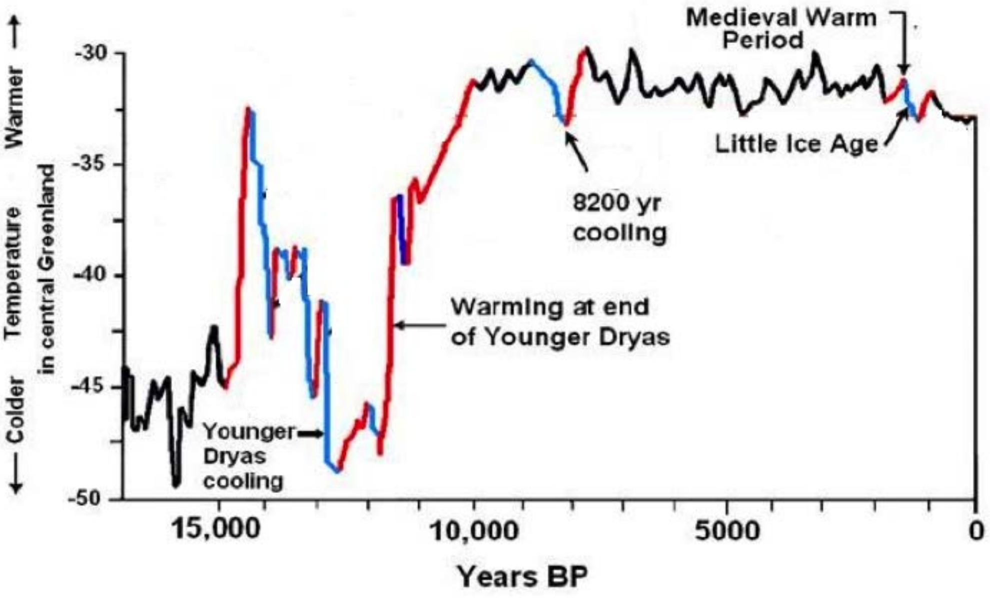


Figure showing the temperature history based on water chemistry (oxygen isotopes) from and ice core in central Greenland. Blue periods are cooling periods and red lines are warming periods that have been studied in other places of the world. This graph does not show the summer warmth of the Pacific Northwest during the early Holocene (11,600 to 8000 years BP). This is because central Greenland was likely buffered from the climatic effects of increased early Holocene summer insolation.

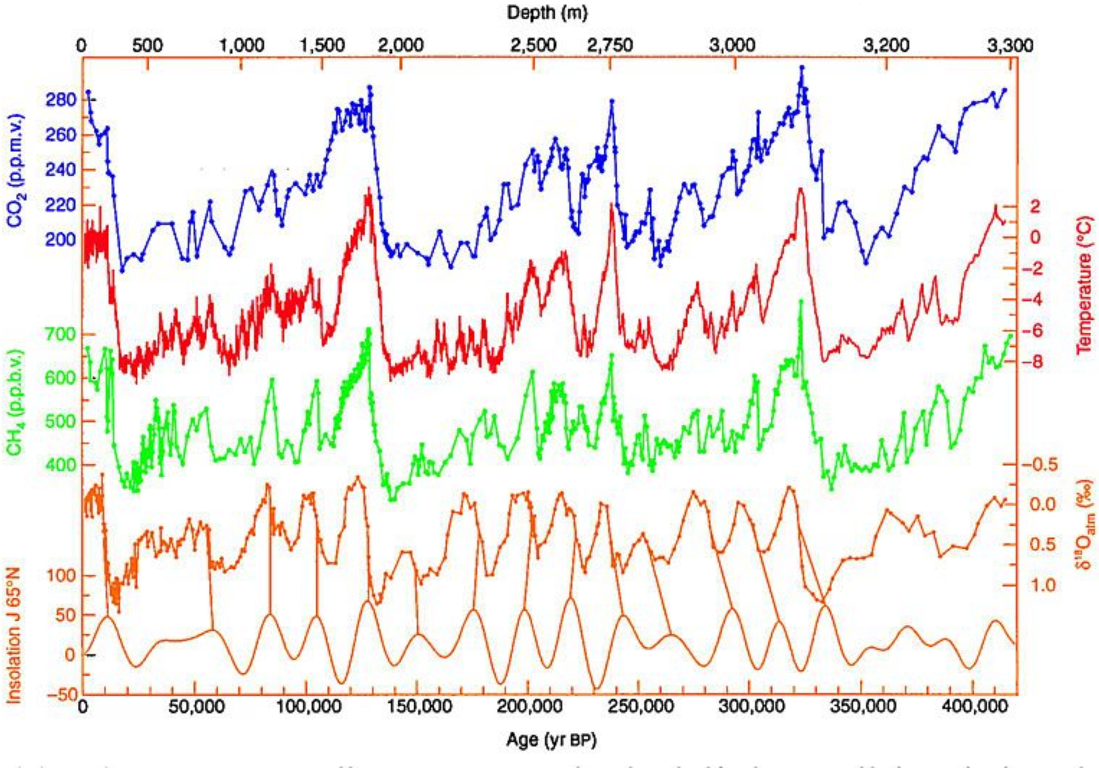
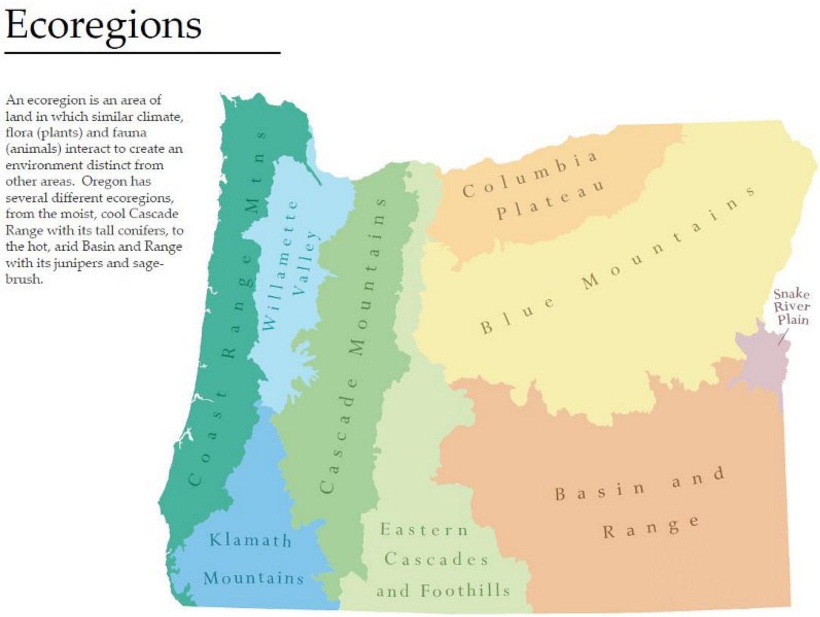


Figure showing the last 420,000 years of ice core data from Vostok, Antarctica This 400,000 year record contains five interglacial periods. (http://commons.wikimedia.org/wiki/File:Vostok_420ky_4curves_insolation.jpg).

Lesson 2: Forest trees and vegetation types of western Oregon



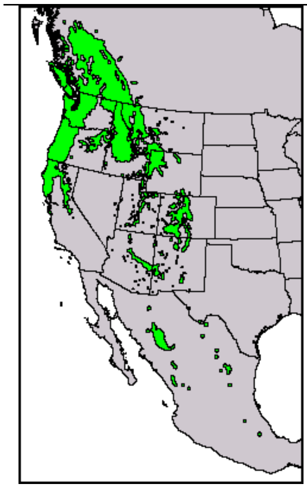
Ecoregions

An ecoregion is an area of land in which similar climate, flora (plants) and fauna (animals) interact to create an environment distinct from other areas. Oregon has several different ecoregions, from the moist, cool Cascade Range with its tall conifers, to the hot, arid Basin and Range with its junipers and sagebrush.

Ecoregion map from Student Atlas of Oregon (http://www.studentatlasoforegon.pdx.edu)

Coast Range Douglas-fir forests

Douglas-fir (*Pseudotsuga menziesii*) is the most common tree in Oregon and is suitably the state's official tree. Douglas-fir is found in a wide range of habitats (see distribution map below). In some environments, such as the Coast Range and western Cascade Range, it is a **pioneer** (early colonizer) species. In these areas Douglas-fir depends on fire and other disturbances to create open patches within the forest where new trees can establish. Douglas-fir needs these open patches because it is shade intolerant (not able to grow in the understory). In this situation, as the forest gets older, firs (*Abies*), western hemlock (*Tsuga heterophylla*), and western redcedar (*Thuja plicata*) become the dominant trees in the forest because they are able to colonize in the understory (below the Douglas-fir) due to their shade tolerance, in a process called **succession**. However, disturbances normally recur at intervals of hundreds of years in the Coast Range, so Douglas-fir remains dominant. Only in the very wet areas of the western Olympic Peninsula, and northward, is fire rare enough that forests become dominated by shade-tolerant species.



Distribution map of Douglas-fir in Central and North America (http://www.conifers.org/pi/Pseudotsuga_menziesii.php).

Douglas-fir can be easily identified in the field (see www.conifers.org for more information and pictures on identification of this species). The tree has thick bark and often develops furrows (cracks) as it ages. The thick bark is also an adaptation for fire resistance, allowing it to survive low and moderate intensity fires. The cones of Douglas-fir have a three-forked elongated bract clearly visible in front of the scales.

The Coast Range forests have a well-developed understory layer of shrubs and herbs including rhododendrons, huckleberry, salmonberry, salal, vine maple, Oregon grape, and thimbleberry. Hardwood trees such as big leaf maple, dogwood, oak, and red alder are also present, but forestry activities have eliminated most species other than Douglas-fir. Ferns (including sword fern, licorice fern, and bracken fern) dominate shaded forest patches and can also be occasionally found on the trunks or branches of trees. Such epiphytes (plants rooted on plants) are abundant in the moister Sitka spruce (*Picea sitchensis*) forests bordering the coast. This species, an indicator of the "coastal temperate rainforest", is common where summer temperature is cool (usually less than 70°F) and rainfall abundant for much of the year.

Willamette Valley Oak Savanna

Oregon white oak (*Quercus garryana*) and the associated prairie plant communities of Oregon's Willamette Valley comprise one of the most endangered ecoregions in North America. An oak savanna is a grassland characterized by scattered trees. This type of environment is found on drier sites within the Willamette Valley and on moist floodplain sites where Douglas-fir cannot tolerate saturated soils. Prior to major European settlement to the valley, wet prairie and oak savanna were very common. Land surveys conducted in the 1850's document about one million acres of the Willamette Valley as prairie and over 400,000 acres as oak savanna. Modern surveys estimate only 10,000 acres (<1%) of the historic extent of the oak prairie savanna remains. Riparian forests of black cottonwood (*Populus trichocarpa*) and willows (*Salix*) were common along the river, and persist today in a few protected areas.

The oak savanna of the Willamette Valley became common in the early Holocene when the climate was both warmer and drier than it is today. Increases of Douglas-fir in oak savanna over the last 100 years are jeopardizing the remaining oak savanna habitat where it still exists (not currently agricultural land). This succession to Douglas-fir supports a widely-held view that a reduction of fire set by Native Americans allowed Douglas-fir to establish, as this species is less fire resistant than Oregon white oak. Other factors also may have prevented Douglas-fir from establishing. For example, lack of fire alone may not be enough to allow Douglas-fir an advantage over grass…but rather the expansion of sheep grazing in the late 1800's removed grass cover and made much bare soil available, the preferred conditions for Douglas-fir establishment. In other areas on the valley floor, the soil is very poorly drained, creating wet meadows that Douglas-fir cannot tolerate. So what was the actual history of the valley? Paleoecological studies should be able to address this question. Not many such studies have been done. Some paleoecological studies have shown a decrease in charcoal (from fire) in lake sediments beginning a few hundred years ago consistent with the Native-American-fire hypothesis, while other paleoecological studies do not provide such support.

Cascade Range subalpine forests

The subalpine forests of the Cascade Range occupy areas that were glaciated during the Pleistocene. This forest type occurs above 3500 feet in elevation where there are still glaciers and permanent snowfields occurring on the highest peaks. Cold winter temperatures and a relatively short growing season due to a persisting spring snowpack favor a completely different set of species than occurs at low elevation. Common trees are mountain hemlock (*Tsuga mertensiana*) and subalpine fir (*Abies lasiocarpa*). Western white pine (*Pinus monticola*) also occurred throughout the mid-elevations, but has been reduced by a fungal disease during the past few decades. The understory consists of only a few herbaceous plants (i.e. bear grass) and small shrubs. The tree species at this elevation are not adapted to surviving fire, so when a fire occurs it often kills all the trees in the area burned. Lodgepole pine (*Pinus contorta*) is also very common and reseeds in large numbers following fire, due to seeds being released from serotinous (seed-release by an environmental trigger such as fire) cones.

Suggested classroom activities and demonstrations:

1. Pass around branches of certain species available in your area. Examine characteristics of needles or leaves that suggest their tolerance for drought (thick waxy leaves) and for growing in the shade (dark green, dense with chlorophyll). Discuss the concept of shade tolerance. We all know plants require light, but some species can tolerate some shade while others cannot. After disturbances such as fire, shade-intolerant species may colonize first, followed by shade-tolerant species that grow in their shade. This change in species over time after disturbance is called **succession**.

Tree species in western Oregon ordered by shade tolerance:

Very shade tolerant	Western hemlock, western redcedar, subalpine fir, Pacific silver fir, mountain hemlock, bigleaf maple
Moderately shade tolerant	Sitka spruce, western white pine
Shade intolerant	Douglas-fir
Very shade intolerant	Red alder, poplars, Oregon white oak, lodgepole pine and shore pine

Tree species in western Oregon ordered by drought tolerance:

Very drought intolerant	Western hemlock, Pacific silver fir, mountain hemlock
Moderately drought intolerant	Western redcedar, Sitka spruce, subalpine fir, bigleaf maple
Drought tolerant	Douglas-fir, western white pine, red alder
Very drought tolerant	lodgepole pine, Oregon white oak

2. Show Google Earth views of western Oregon, showing the pattern of vegetation distribution (shades of brown and green) and discuss students' experiences with climate in different areas of western Oregon.

Lesson 3: Tools of paleoecology: coring, sediment processing, and pollen analysis

Questions to be considered:

- How do scientists know that Earth's climate has changed?
- How are sediment cores obtained?
- How is pollen isolated and identified?

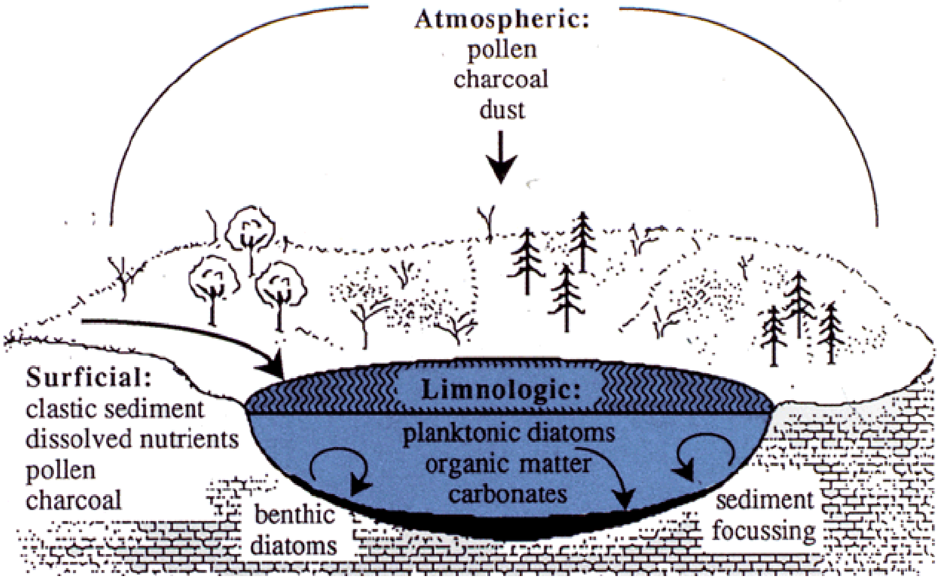
Classroom demonstrations and activities:

- Show video of the coring of lake sediments
- Show PowerPoint slides of laboratory work in preparation of pollen samples.

Paleoecologists study how communities of plants and animals have changed through time in response to changing conditions such as climate change. Paleoecologists examine fossils (preserved parts of once living organisms—either the actual part of the plant such as pollen and seeds, or an imprint of the part such as footprints or leaf prints). These fossil records can be found in lakes, bogs, and packrat middens. Within these records, bones, teeth, insects, pollen, seeds, leaves, and chemical traces can provide information on past environments. Some of the best records, with a high number of fossils and a good time-sequence of events, come from lake sediments.

Paleoecologists who examine fossil pollen are called **palynologists**. All vascular plants produce pollen or spores. Pollen can be identified taxonomically to the family, genus, and occasionally species level. A **pollen assemblage** is the relative amounts of distinct pollen types in a sample (for example, a lake sediment sample). Changes in plant populations can be inferred from changes in the pollen abundance through time.

Fossil pollen is most commonly obtained from lake sediments. Pollen, charcoal, and several other materials that are blown or washed into a lake become incorporated and preserved within sediments at the bottom of the lake. Lakes are continually filling with sediments, preserving a record of vegetation and climate change. If left undisturbed, the sediments preserve an environmental history, with the oldest sediments at the bottom and the youngest at the top.



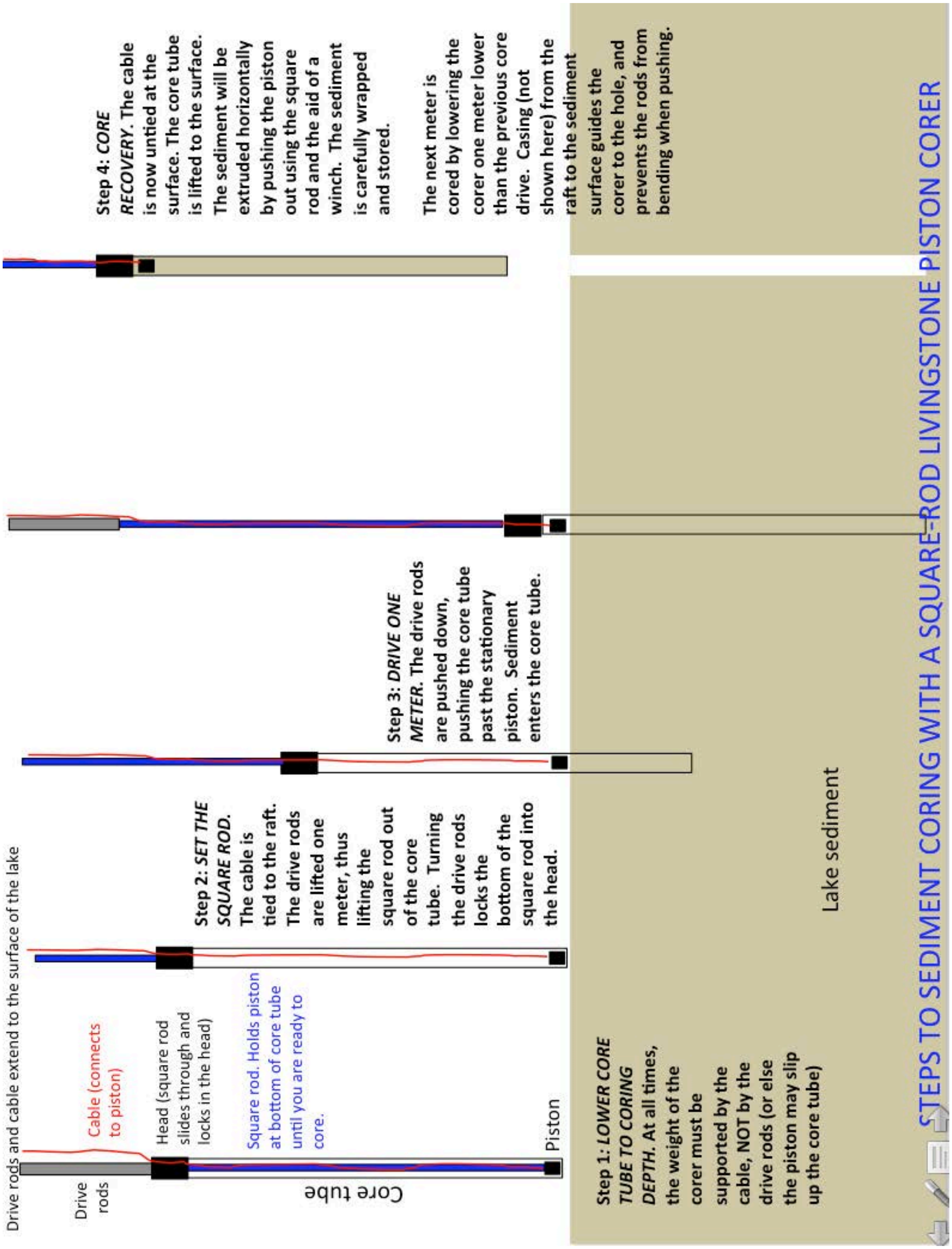
Sediment cores are obtained using methods that produce a continuous undisturbed sequence of sediment in several overlapping one-meter lengths. A coring device called a **Livingston piston corer** is used to sample the sediments from the bottom of a lake. Casing (pipe about 4 inches in diameter) from the lake surface to the lake bottom allows the Livingstone corer to return to the same hole. A piston prevents sediment from entering the core tube until the desired core depth is reached. Then, the piston is held stationary by a cable extending to the surface. Rods are used to push the core tube past the piston, and the sediment sample enters the core tube. The corer is lifted to the surface, the sediment core is extruded (pushed out of the core tube) and wrapped and labeled. The corer is cleaned and returned down the casing to retrieve the next meter. In general, for a small lake, one meter will represent about 2000 years. This coring system can obtain about 13 meters of sediment before coring becomes too difficult, but normally lakes less than 15,000 years old contain less than 10 meters of sediment.

The sediment cores are taken back to the laboratory for analysis. The sediment is stored in a cooler to prevent decomposition of the organic matter and to prevent it from drying. The cores are split in half lengthwise. Half of the core is archived for future studies. The other half of the core can be used for several types of analyses.

Pollen records provided some of the first evidence used to study past climate, but today there are many other **proxies** (things measured to approximate something else) for **paleoclimatology**. Pollen is a proxy of vegetation; some lake-sediment chemistry measures (isotopes, for example) may be good proxies of climate. Pollen records, though, provide a history of how vegetation responded to past climate, and thus how it may respond to future climate change.

Samples of sediment are taken at intervals down a core. These samples, normally 1 cm^3, are processed to eliminate most other material except pollen, which is made of a highly resistant substance (sporopollenin). Sporopollenin is resistant to strong acids that can dissolve sands, and to strong bases that can dissolve organic matter. The processing of pollen must take place in a fume hood because hazardous chemicals are used to eliminate organic and inorganic substances. Each chemical wash concentrates the amount of pollen within each sample making it easier to count.

Sediment cores are dated by radiocarbon dating organic matter, ideally an identifiable leaf, seed, or needle. As little as 100 mg of material may be used to obtain a radiocarbon date. See the text by Pielou (After the Ice Age) for an introduction to radiocarbon dating of lake sediments.



Step 1: ***LOWER CORE TUBE TO CORING DEPTH.*** **At all times, the weight of the corer must be supported by the cable, NOT by the drive rods (or else the piston may slip up the core tube)**

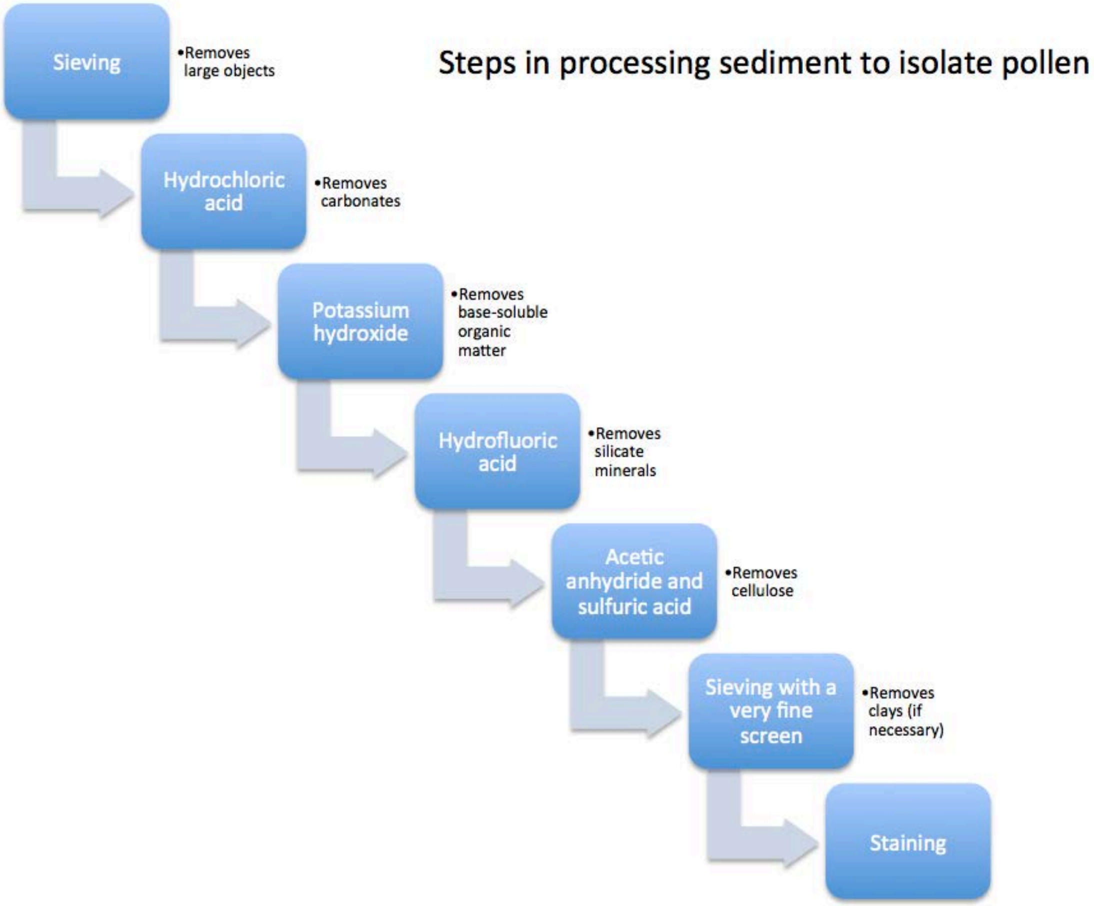
Step 2: ***SET THE SQUARE ROD.*** **The cable is tied to the raft. The drive rods are lifted one meter, thus lifting the square rod out of the core tube. Turning the drive rods locks the bottom of the square rod into the head.**

Step 3: ***DRIVE ONE METER.*** **The drive rods are pushed down, pushing the core tube past the stationary piston. Sediment enters the core tube.**

Step 4: ***CORE RECOVERY.*** **The cable is now untied at the surface. The core tube is lifted to the surface. The sediment will be extruded horizontally by pushing the piston out using the square rod and the aid of a winch. The sediment is carefully wrapped and stored.**

The next meter is cored by lowering the corer one meter lower than the previous core drive. Casing (not shown here) from the raft to the sediment surface guides the corer to the hole, and prevents the rods from bending when pushing.

Schematic diagram showing the steps of obtaining a lake sediment core using a Livingstone piston corer.



Steps in processing sediment to isolate pollen

Lesson 4. Developing a pollen diagram from a sediment record

Questions to be considered:
What is a taxonomic (dichotomous) key?
What are the main features of pollen?

Classroom demonstrations and activities:
Demonstrate the use of a dichotomous key.
- Show a photograph of one of the pollen types and show how the key is used to identify an unknown pollen grain.

Show photographs of the six pollen types to be studied and point to their main anatomical features. With only six pollen types, the dichotomous key is not necessary once the students learn the key features of each pollen type. However, it can be pointed out that the key is indeed useful when there are potentially hundreds of pollen types.
Count at least 100 grains of pollen on prepared pollen slides.

The background information for this section was discussed in Lesson 3. The following information is a how-to guide for calculating pollen percentages and creating pollen diagrams.

Materials needed:
Pollen slides representing time periods (depths in the sediment core; 1 slide for every 2 students).
1 compound microscope for every 2 students
1 calculator for every 2 students
Each student needs a blank paper for tallying pollen types.

Background

Palynologists normally identify at least 350 pollen grains in each pollen sample. This is enough pollen to determine the relative proportion of each pollen type with good accuracy. Palynologists must be able to identify hundreds of pollen types, but in practice only 20 to 30 pollen types are commonly encountered. Pollen can be identified by its morphological characteristics, including its overall shape, size, pores, furrows (creases), and the sculpturing of the wall of the pollen grain.

In this lesson, students work with prepared pollen slides that contain prescribed proportions of six distinct pollen types. The slides have been prepared to represent an actual pollen record from Little Lake, located near Triangle Lake in Lane County, Oregon. A landslide created Triangle Lake and Little Lake about 45,000 years ago. For this exercise, we are calling our fictitious sample site "Square Lake". The slides have been prepared using fairly pure mixtures of pollen without any of the "junk" that is mixed in with pollen when prepared from sediment samples. This greatly simplifies pollen identification, which will be challenging enough for students new to using microscopes. See the end of this lesson for suggestions on how to develop your own microscope slides.

Prior to the students using the microscopes, the basic morphology of pollen grains must be taught, including the use of the taxonomic key. See the PowerPoint presentation for the key aspects of pollen identification.

Pollen identification

Students will work alone or in pairs at a microscope. Each group is assigned a pollen slide. Focus the slide under increasingly larger objective lenses. Count and record the number of each type of pollen that you see in the field of view. Move to another field and repeat the process. Each student should count five fields-of-view before trading off with a partner. Students should work collaboratively at identifying pollen grains.

If nine groups complete about 100-grain pollen counts, then a pollen diagram may be completed.

Determine the total number of grains counted of each type and enter in the Type total column. Then, add together the Type totals to determine the Pollen Total (this should be more than 150 pollen grains). Then, determine the percentages of each pollen type by dividing each Type Total by the Pollen Total and multiplying by 100. Enter this in the gray column.

Acknowledgements

Inspiration for this exercise came from:

Lyford, M. E. and J. M. Beiswenger. 2000. Paleoecology as a Classroom Tool to Address Global Climate Change. Pages 324-338, *in* Tested studies for laboratory teaching, Volume 21 (S. J. Karcher, Editor). Proceedings of the 21st Workshop/Conference of the Association for Biology Laboratory Education (ABLE), 509 pages.

Creating microscope slides of pollen mixtures.

This information is provided if a teacher wishes to customize this lesson to their local area.

Collect pollen: Slides may be made from collecting fresh pollen in the field, or by obtaining pure pollen extracts provided by allergy research company. Hollister-Stier in Spokane, WA, for example, can sell vials of pure pollen for dozens of species.

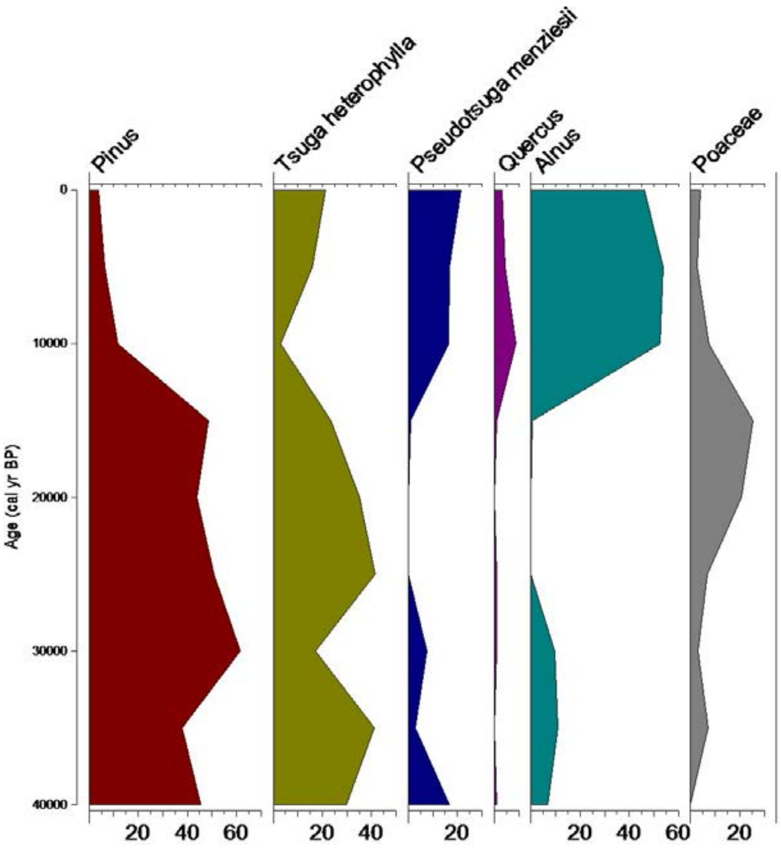
Process pollen: In this step, we assume some prior experience with the chemical processing of pollen samples. If using fresh field-collected material, anthers should be sieved and pollen should be treated by acetolysis. If using pollen provided by a company, it may be possible to skip acetolysis. Stain samples when in water using Safranin (a very dilute mixture as it is easy to darken the grains so that features are no longer visible). Then, rinse with ethanol and tert-butyl alcohol (TBA).

Determining pollen concentrations: When in TBA, take a very small aliquot (15 µl) of TBA/pollen mixture immediately after stirring the sample. Place on a microscope slide and make a complete count of the pollen grains. Repeat three times and use the average concentration. Then, it is possible to calculate the required volume of each species (in TBA solutions) to mix for a target relative percentage of each pollen type. Once a set of mixed pollen samples are made, centrifuge and remove the TBA, then add Si oil.

Create permanently mounted pollen slides: Add a small amount of sample in Si oil on a warm microscope slide (we work on a heat block turned to its lowest setting). Add a round cover slip over the sample. The Si oil will spread out under the entire area of the cover slip, but before the Si oil reaches the edges place a drop of melted paraffin at the crack between the cover slip and the slide. Repeat at two or three locations around the cover slip, and remove from heat. You should see the paraffin solidify around the perimeter of the cover slip.

Lesson 5. Constructing and interpreting a pollen diagram

Questions:
How has vegetation changed through time in the Oregon Coast Range?
How has vegetation of the region changed through time?
From what we know about the vegetation, how has the climate changed through time?



An example pollen diagram from "Square Lake". The vertical y-axis indicates time (in "calibrated radiocarbon years before present", and on each graph the horizontal x-axis indicates the percentage of total pollen that is of that pollen type. *Pinus*=pine, *Tsuga heterophylla*=western hemlock, *Pseudotsuga menziesii*=Douglas-fir, *Quercus*=oak, *Alnus*=alder, Poaceae=grass.

Interpreting pollen diagrams is a fun and tricky process. Each graph can be viewed individually, showing the trend in that species through time. Each time-slice can also be viewed individually, showing the assemblage of species occurring at any one time.

Pollen of a particular species may be **over-represented** or **under-represented**. Over-represented species, such as pine and alder, produce a lot of pollen that is very efficiently wind-dispersed. Under-represented species produce heaver pollen grains that may not be that well wind-dispersed. For example, Douglas-fir is slightly under-represented because the grain is not very buoyant in the air. Maples are mostly insect-pollinated and may never contribute much pollen to lakes unless they are the dominant species of a forest (such as occurs in the eastern United States).

Pollen data expressed as percentages may be misinterpreted. Consider a forest of maple trees that does not contain any pine. Pine then invades a small rocky outcrop near the lake shore, and suddenly pine pollen percent increases from 0 to 40%, and maple pollen percentages therefore decrease. Maple pollen percent decreased only because there was an increase in the **over-represented** species on the landscape, not because maple trees actually decreased on the landscape. The absolute amount of maple pollen entering the lake would have remained unchanged. It is possible to present pollen data in terms of absolute accumulation rates…in units of grains of pollen deposited on one square centimeter of sediment per year. These values may be over 1,000 pollen grains per square centimeter per year! This would seem like a perfect alternative to using pollen percentages, and not subject to those data misinterpretations. However, to calculate a pollen accumulation rate, one needs to know the concentration of pollen in the sediment (grains per cubic centimeter) and the sedimentation rate (centimeters per year). Both of these values can be estimated, but are subject to several sources of error. These sources of error are not an issue when expressing pollen in terms of relative amounts (pollen percentages). A good description of this problem is presented in Pielou's book After the Ice Age, pages 54-56.

Students should attempt to describe the forests through time—how did the vegetation change from the period before the LGM, to the LGM, to the early Holocene, and then to the late Holocene? Which species were completely absent in the past? See questions at the beginning of this lab.

Lesson 6: Exploring paleoecological data using web-mapping tools

This lesson is contained entirely in the document of materials for students.

References (some of these will be included on the flash drive given out at the workshop)

The pollen-analysis exercise was inspired by:

Lyford, M. E. and J. M. Beiswenger. 2000. Paleoecology as a Classroom Tool to Address Global Climate Change. Pages 324-338, *in* Tested studies for laboratory teaching, Volume 21 (S. J. Karcher, Editor). Proceedings of the 21st Workshop/Conference of the Association for Biology Laboratory Education (ABLE), 509 pages.

Paleoecology of the Pacific Northwest

Brubaker, L. B. 1991. Climate change and the origin of old-growth Douglas-fir forests in the Puget Sound Lowland. Pages 17–24 *in* L. F. Ruggiero, K. B. Aubry, A. B. Carey, and M. H. Huff, editors. Wildlife and Vegetation of Unmanaged Douglas-fir Forests. USDA Forest Service, Pacific Northwest Research Station, Portland, OR.

Leopold, E. B., and R. Boyd. 1999. An ecological history of old prairie areas, southwestern Washington. Pages 139–166 Indians, Fire and the Land. Oregon State University Press, Corvallis OR.

Whitlock, C. 1992. Vegetational and climatic history of the Pacific Northwest during the last 20,000 years: implications for understanding present day biodiversity. Northwest Environmental Journal 8:5–28.

Worona, M. A., and C. Whitlock. 1995. Late Quaternary vegetation and climate history near Little Lake, central Coast Range, Oregon. Geological Society of America Bulletin 107:867 –876.

General paleoecology—somewhat dated but very accessible

Pielou, E.C. 1991. After the Ice Age. University of Chicago Press.

Vegetation of the Pacific Northwest

The introductory pages, and tree descriptions, in:
<u>Plants of the Pacific Northwest Coast: Washington, Oregon, British Columbia and Alaska</u>
by Jim Pojar.